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MEASUREMENT OF WIND AND TEMPERATURE IN THE UPPER ATMOSPHERE

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MEASUREMENT OF WIND AND TEMPERATURE
IN THE UPPER ATMOSPHERE

II. Treatment of Data

Resume

After explaining the methods used to plot the wind, including the limits and the accuracy achieved, we examine the corrections which apply to the terms of the general equation of equillibrium of a thermistor.

The limited values of these corrections as functions of the sounding conditions are estimated and compared among themselves to determine the most suitable methods of exploitation.

1. Introduction

In a preceding publication [1], the material of sounding by rocket used in France is described and the values of the main parameters most likely to influence the results is discussed.

The purpose of this article is to evaluate the corrections which apply to data received and to describe the treatment of information which enables us to obtain the final values for the wind and temperature.

This material has been conceived to use a direct temperature measurement sensor for which the time factor will be as low as possible.

A heat resistant wire 5 μ in diameter and 20 mm in length is used. The calorific capacity of such a sensor is reduced the minimum compatible with adequate mechanical strength and its geometry, although unfavorable as concerns the influence of solar radiation, presents characteristic dimensions such as are found under conditions of discharge of free molecules over the

35 km level, which facilitates the determination of the coefficients necessary to calculate certain corrections.

Evaluation of most corrections depends on parameters which vary with the conditions encountered in sounding and whose measurement is either difficult to achieve or imprecise. Instrumentation has been developed to minimize as much as possible the absolute values of these corrections while preserving sufficient precision:

-- either ignoring all but the highest levels possible,

-- or calculating them using graphs or tables which furnish the standard values of these parameters independent of the conditions of launch up to the highest possible levels.

Throughout the rest of this article, each parameter which interferes with the calculations of final air temperature will be represented graphically as a function of altitude, from 45 km to 80 km, in the form of two curves specifying the extreme values which the function can take:

-- seasonal variations of the physical parameters of the atmosphere (the extreme values used as references are those shown in "U.S. Standard Supplement 66" for the months of July and January for 45° north latitude),

-- functioning of launch instrumentation (a statistical study has been made on a selection of 40 soundings judged representative of normal launch conditions),

-- conditions of launch: proper arrangement of the launch site to maintain the same nominal azimuth which produce extreme values of the velocity of the sensor in relationship to the atmosphere which varies, at high altitudes, between summer and winter conditions.

In this work, all the values considered are relative to the soundings made in France at 45° N with a launch azimuth of 270° and leveling off at altitudes between 80 and 85 km.

The comparison of extreme values of corrections as functions of altitude will permit us to ascertain two methods of analysis which are useful for the levels considered

-- one very simplified method not varying from the "standard values" common to all launches and velocity V of the sensor in relation to the atmosphere at levels less than 65 km;

-- a more complex method which requires the estimation of certain parameters of the atmosphere for each launch at levels above 65 km.

II. Determination of the Wind

When a meteorological rocket approaches its apogee, it ejects a probe which descends suspended from a metal-plated parachute whose trajectory is plotted by radar by skin tracking.

The vector "horizontal velocity V_{hp} of the parachute in relation to the observer" is compared to the horizontal velocity vector V of the true wind.

With the great horizontal velocities of ejection, the fluctuations of the drag factor and of the inertial forces of the parachute become apparent as differences between the two vectors at levels over 50 km and necessitate the application of corrective terms whose value increases rapidly with altitude.

Suppose [3], [4] that:

-- the parachute is subject solely to forces of gravity and resistance of the atmosphere;

-- the force of gravity is constant;

-- the amplitude $|D|$ of the resistance to forward motion is proportional to the square of the velocity of the parachute in relation to the atmosphere;

and with

m = mass of the "probe-parachute" system;

$\frac{d\vec{Vp}}{dt}$ = the acceleration of the parachute in relation to an observer;

$\vec{V}_H$ = the horizontal velocity of the wind in relation to an observer;

$\vec{g}$ = the acceleration of gravity;

$\vec{D}$ = force of resistance to forward motion;

ρ = the density of the air;

C_d = coefficient of resistance to forward motion of the "probe-parachute" system;

S = effective surface of the parachute;

u = velocity W.E. of the wind;

v = velocity S.N. of the wind;

w = vertical velocity of the wind;

u_p = velocity W.E. of the parachute;

$\dot{u}_p$ = acceleration W.E. of the parachute.

We can write:

$$m. \frac{d\vec{V}p}{dt} = m.\vec{g} + \vec{D} \tag{1}$$

$$|\vec{D}| = \frac{\rho . S . C_d}{2} (\vec{V} - \vec{V}_p)^2 \tag{2}$$

For the case where $\omega << \omega_p$, we derive the expression with correctec terms to apply to the horizontal components of the velocity vector of the parachute to obtain the components of the wind vector

$$\Delta u = - \omega_p \frac{\dot{u}_p}{\dot{\omega}_p + g} \tag{3}$$

$$\Delta v = - \omega_p \frac{\dot{v}_p}{\dot{\omega}_p + g} \tag{4}$$

The corrective terms are considered significant until the parachute leaves the level where it is sensitive to the wind, i.e., when the force of resistance to forward motion attains a certain order of magnitude (equation 1). This level is characterized by deviations of the horizontal projection of the trajectory of the parachute, and study of a large number of soundings permits the definition of this level as that when the vertical acceleration of the parachute becomes less than 5 $m \cdot s^{-2}$ which, for an apogee of 85 km, limits the measurement of the altitude to 80 km.

Table 1 shows, for example, that the level is established at around 78 km for a sounding taken with a parachute 4.3 m in diameter, a total mass of 1.5 kg and a culmination altitude of 83.3 km.

For this sounding, table 2 provides a value of corrective terms $\Delta u = u - u_p$ and $\Delta v = v - v$ as a function of altitude as the difference between the calculated wind vector V and the horizontal velocity vector of the parachute V_{hp}.

The percentage of error which would be made without these corrections is listed in the right column.

Figure 1 shows the values of u and u_p, composed W.E. of wind vector V and of vector V_{hp}; Figure 2 shows the values as functions of the altitude of the modulus of the vectors:

-- velocity of wind V;

-- horizontal velocity of the parachute in relation to an observer: V_{hp};

-- vertical velocity of the parachute: V_z;

-- vertical velocity of the parachute V_g when $|\vec{D}| = 0$ as the vertical acceleration of the parachute Γp_z varies from 83 to 76 km.

The value of the terms Δu and Δv can reach 100 m/s^{-1} at the highest levels and decreases very rapidly to less than 1 m/s^{-1} over 50 km.

A high performance radar is necessary in order that the errors due to imprecision of the data be small in relation to the value of the corrective terms (3) and (4).

The radars used have an accuracy of azimuth and elevation of 2.10^{-4} rad and an accuracy of tens of meters in estimation of distance which satisfies the conditions established by Hyson [2].

The entire operation thus has an accuracy better than 1 m/sec in the estimation of the vector V and an uncertainty less than 3 m/sec in the calculation of corrective terms similar to the case of very strong and rapidly changing winds. Finally, we can measure the winds with an accuracy of 3% for levels above 70 km and 2% or less for levels above 65 km.

III. Determination of Temperature

A = Effective surface of sensor

A1 = Effective surface of sensor for solar radiation

A2 = Effective surface of sensor for radiation near the Earth or cloud cover

A3 = Effective surface of sensor for radiation near the atmosphere above the probe

A4 = Effective surface of sensor for radiation near the probe

C = Specific heat of wire

D = Diameter of wire

I = Solar constant

K = Coefficient of kinetic heating

R = Resistance of wire

T1 = Temperature of Constantan wire (soldering level)

T2 = Temperature equivalents of black bodies for the atmosphere or the cloud cover

T3 = Temperature equivalents of black bodies for the atmosphere above the probe

T4 = Temperature equivalents of black bodies for the probe

Te = Air temperature

T_f = Average temperature of the wire
T_{fx} = Temperature of the wire at distance X from the ends
T_s = Temperature of supports
V = Velocity of sensor in relation to the air
W = Energy of "current measurement" dissipated by the sensor
c_p = Specific heat at constant pressure
h = Convective dissipation factor
i = Electric current in the wire
k1 = Absorption factor solar radiation sensor
k2 = Absorption factor of long wave radiation sensor
l = Length of wire
r = Recovery factor
α = Coefficient of adaptation
σ = Boltzman's constant
Σ_i = Radiation other than solar
Σ_s = Solar radiation

3.1. General Equation of Equillibrium of a Wire of 5 μ

Knowing the average temperature T_f of the wire, we find a relationship which permits us to calculate the temperature T_e of the nonperturbed atmosphere whose temperatures are limited by the equation

$$m.C \frac{dT_f}{dt} = Q + R + J + S + N \tag{5}$$

These symbols represent the thermal exchanges relative to:

-- convection = $Q = A.h(T_f - T_e)$
-- radiation = $R = k_1\Sigma_s A_1 + \sigma k_2(A_2T_2^4 + A_3T_3^4 + A_4T_4^4 - AT_f^4)$
-- heating by the Joule effect = $j = R_i 2$
-- kinetic heating = $S = K.h.A.V^2$
-- conduction = $N = K'(\delta^2 T_{fx}/\delta x^2) = f(T_e, T_s, T_f)$

The same equation (5) applies to Constantan wire for the calculation of the application of heat by conduction.

TABLE 1

Z km	$\|\vec{V}_z\|$ m.sec^{-1}	$\|\vec{V}_{ph}\|$ m.sec^{-1}	$\|\vec{V}_g\|$ m.sec^{-1}	T_p m.sec^{-2}
83,3	0	272	0	
83	68	265	76	9,1
82,5	120	247	123	9
82	149	236	157	8,2
81,5	176	222	185	6,9
81	189	212	209	7,1
80,5	215	202	230	7,03
80	222	198	250	5,0
79,5	236	195	268	4,2
79	240	179	286	4,1
78,5	253	165	302	5,5
78	262	166	317	3,1
77,5	265	158	332	2,7
77	272	153	346	1,4
76,5	270	140	360	0
76	270	130	373	0

$|\vec{V}_z|$ = vertical velocity vector module of the parachute

$|\vec{V}_{ph}|$ = module of the horizontal velocity vector of the parachute

$|\vec{V}_g|$ = module of vertical velocity vector of the parachute with $|\vec{D}| = 0$

T_p = vertical acceleration of parachute (mean value for 1 km)

Sounding of 16 December 1971

Parachute: diameter, 4.30 m; total mass 1.6 kg; apogee, 83.3 km.

TABLE 2

Z	U	Δu	V	Δv	$\|\vec{V}_{ph}\|$	$\|\vec{V}\|$	$\|\vec{V}\| - \|\vec{V}_{ph}\|$	erreur %
78	-116	32	41	115	166	123	-43	-26%
75	- 60	34	+18	73	109	63	-46	-42%
70	32	34	12	32	20	32	12	+60%
65	160	47	-17	- 5	114	163	49	+43%
60	129	-14	16	12	143	130	-13	- 9%
55	138	- 3	12	1	141	139	- 2	- 1%
50	133	2	- 1	- 1	133	132	- 1	-0,8%
45	126	- 2	-12	- 1	129	126	- 3	- 2%
40	82	1	-23	1	85	85	0	0%

Sounding of 16 December 1971

Parachute: diameter 4.30 km; total mass, 1.6 kg; apogee, 83.300 m

Horizontal velocity at apogee: 272 m/sec.

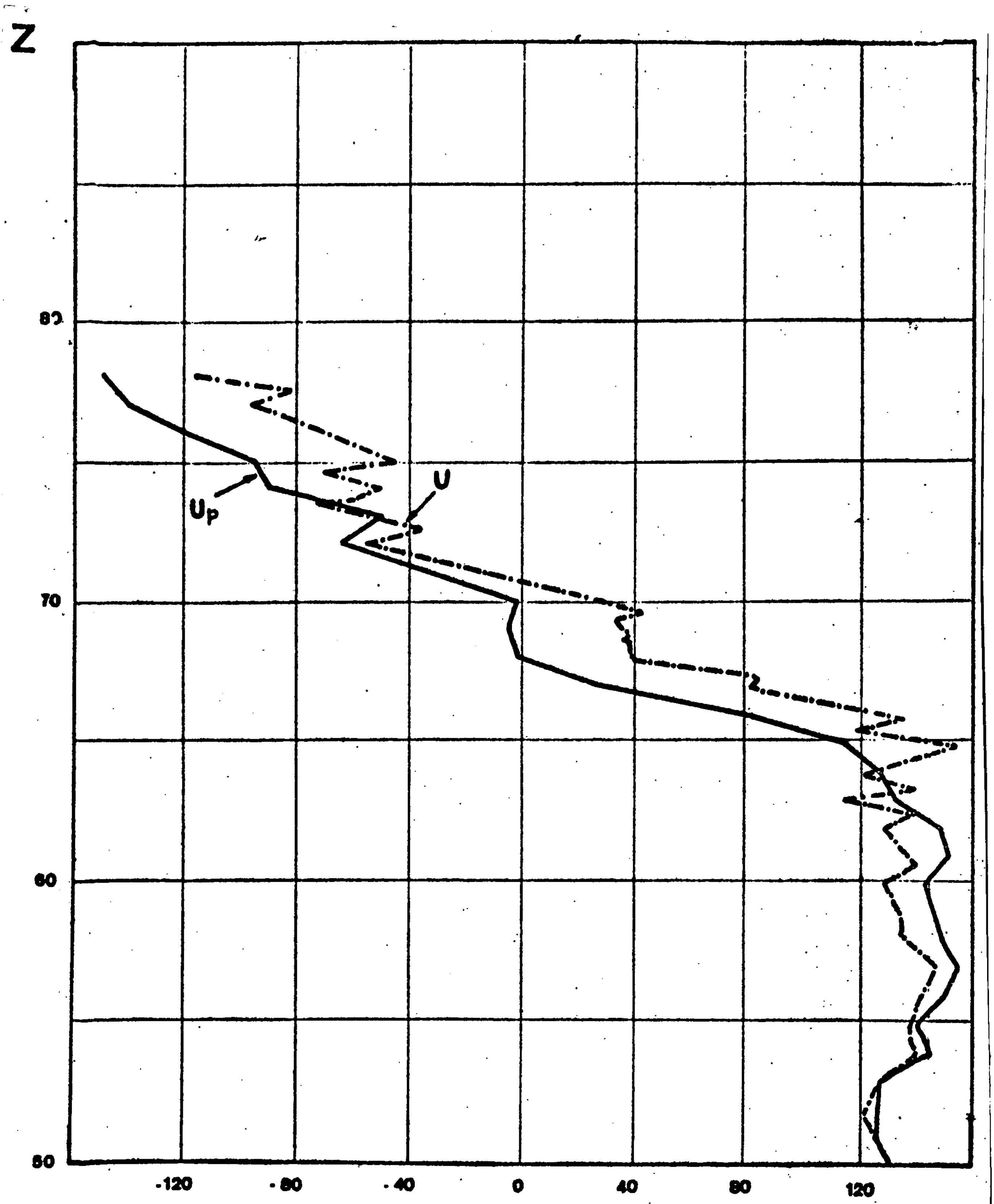

Figure 1. Velocity W.E. (m/sec)

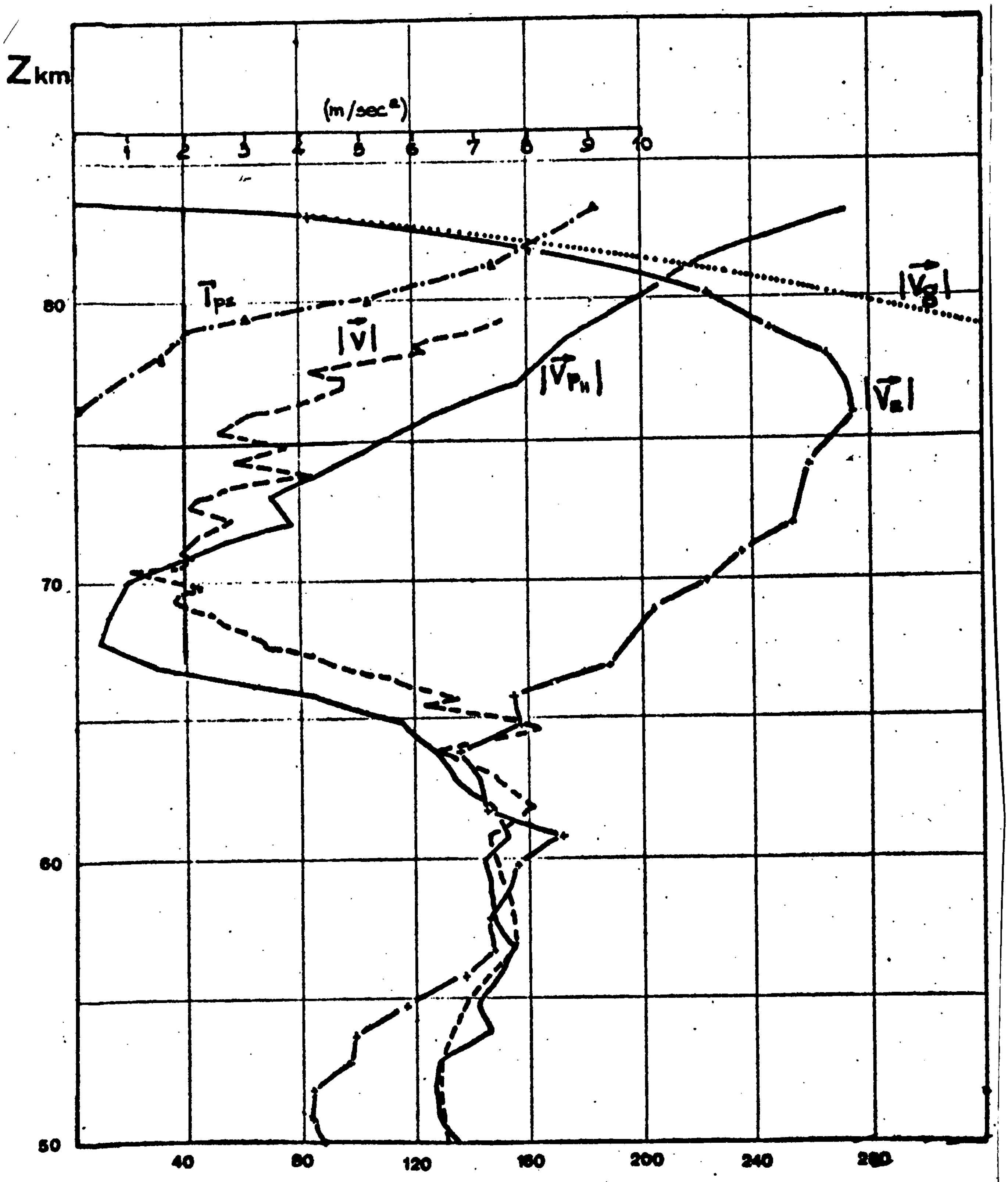

Figure 2. Velocity (m/sec)

Heating by the Joule effect does not take into account the measurement current; high frequency effects near the transmitter have been found to be negligible experimentally.

The ratio of the diameter of the wire to its length allows us to consider the transverse and longitudinal temperature distribution to be uniform for the major part of the sounding. We can thus consider the problem of thermal equillibrium of the sensor by considering the wire as a cylinder of infinite length.

The equation becomes

$$\Delta T = T_f - T_e = K.V^2 + \frac{\Sigma_s}{A.h} + \frac{Ri^2}{A.h} + \frac{\Sigma_i}{A.h} - \frac{c}{A.h}\frac{\delta T_f}{\delta t} + K' \frac{\delta^2 T_f}{\delta x^2} \quad (6)$$

To solve this general equation, it is necessary to determine a certain number of coefficients of which the values and variations depend on the nature of the sensor used and the conditions under which the measurement is taken:

-- the coefficients of absorption of a 5 μ gilded wire have been determined experimentally;

-- the temperatures used in the radiation balance between the wire and the surrounding environment are those indicated by Wagner [5];

-- the values of the density ρ and temperature T used in the first approximation are the values of the "U.S. Standard Supplement Atmosphere 45 N January and July;"

-- the values of velocity in relation to the atmosphere (V) are calculated as part of the trajectory (see II. Determination of Winds). The curves representing the values of V have been traced on Figure 3 to indicate the extreme values observed at the Centre d'Essais des Landes.

-- the value of the temperature of supports $T_s(\phi)$ is an average determined experimentally by direct measurement during actual soundings.

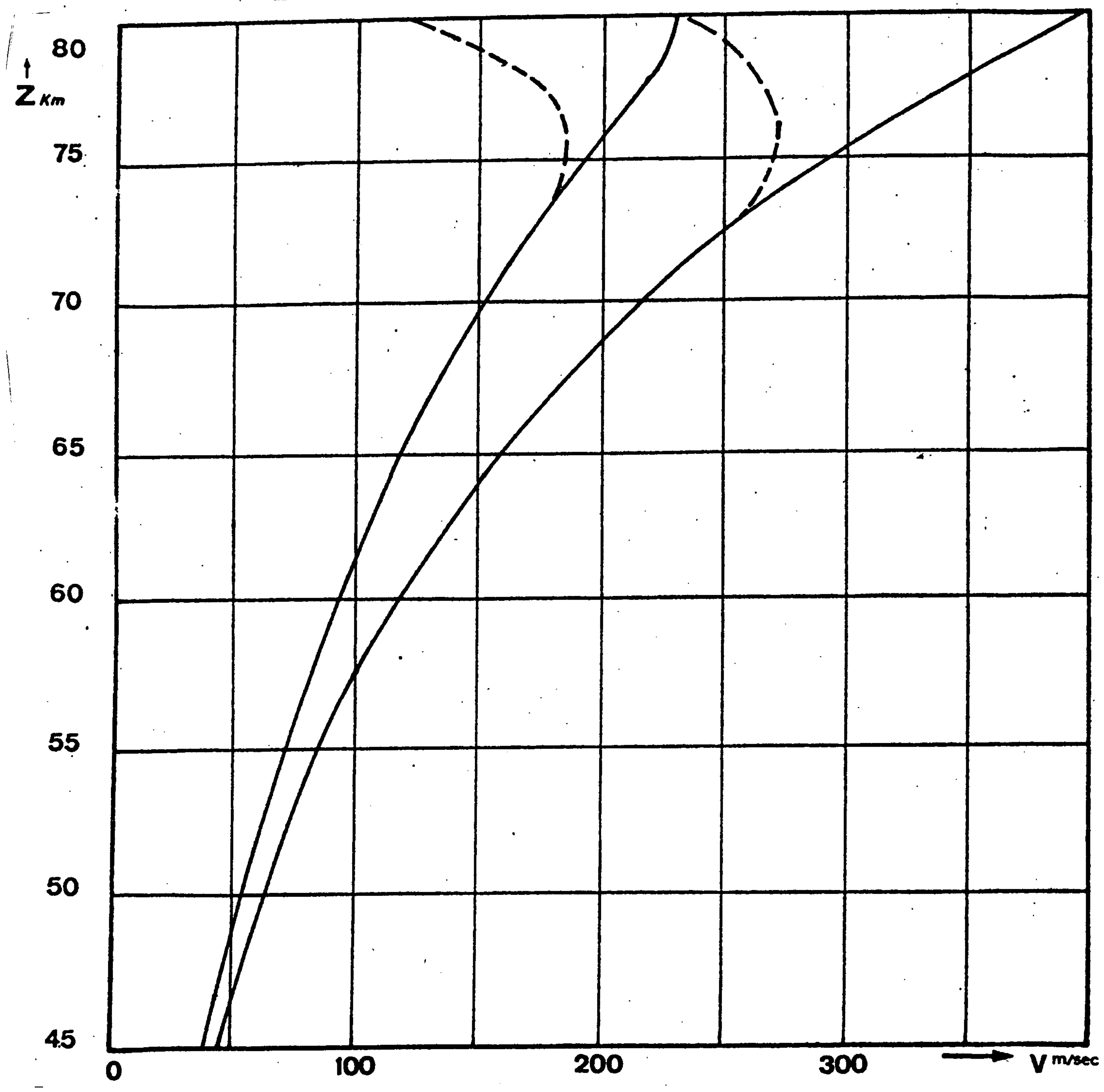

Figure 3. Velocity of the Sensor in Relation to the Atmosphere
-- Minimum and maximum values established after a launch at 84° nominal site and 270° azimuth
-- Horizontal velocity of descent: 300 m/s for 80 km apogee; 250 m/s for 85 km apogee
-- Winter launch: ________; summer launch: --------

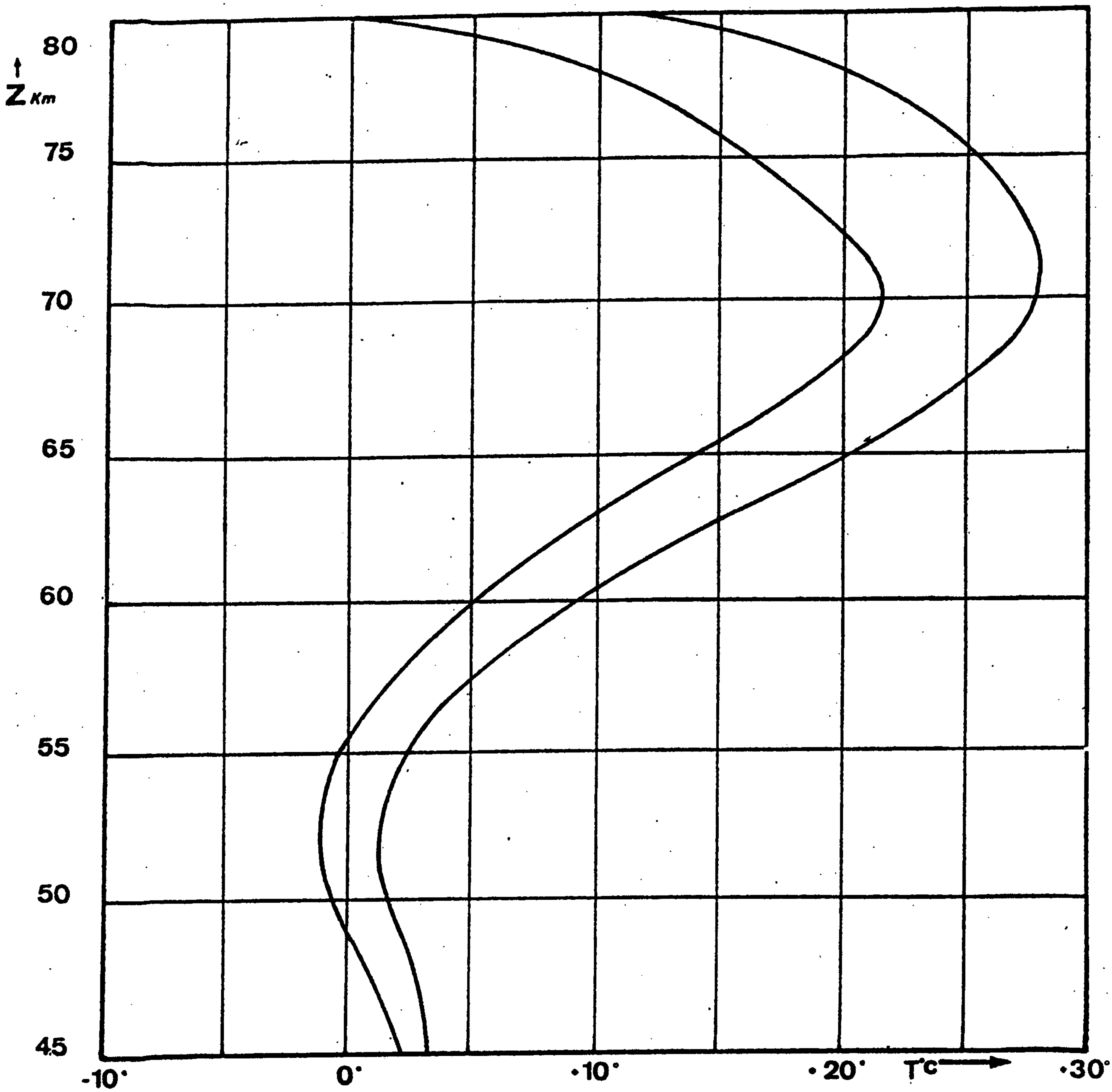

Figure 4. Maximum and minimum values of deviation of temperatures of the supports (T_s) and of the wire (T_f)

The extreme values of the difference between the temperature of the supports and that of the wire (T_s - T_f) are shown on Figure 4.

-- After Oppenheim [6], the coefficient of dissipation h is a function of density, temperature and velocity in relation to the atmosphere. Variations in terms of density have been determined experimentally for the wire, and the variations as a function of velocity have been deduced in [6]. Table 3 shows the relative variations of h in terms of velocity, and Figure 5 presents these variations in terms of the extreme values of velocity, temperature and density (seasonal variation).

-- The coefficient K has been determined experimentally for variable velocities up to 250 $m.s^{-1}$.

3.2. Estimation of Corrections

3.2.1. High Frequency Radiation

The power radiated by the transmitter antennas has been limited in such a way as to diminish the energy received by the sensor. Some laboratory experiments have been performed by placing the sensor assembly in a small chamber under very low pressure (less than 10^{-2} torr). No matter what position the antennas had in relation to the sensor, its temperature never reached above 1°C.

3.2.2. Telemetry

The telemetry has a resolution of 1 Hz per 0.2°C. It transmits continuously the frequencies coming from the frequency-resistance converter containing the thermistor.

The influence of low temperatures on the electronic components can, under 30 km, cause drift of these frequencies.

The modules are designed such that the drift is monotonous and continuous and remains less than 10 Hz during the entire time of sounding. Two resistors, with very low temperature factor (7 p.p.m.) for values corresponding to the extreme values of the resistance of the sensor, alternate for 15 seconds every 8 minutes and permit correction of this drift during sounding with a precision of about 1/10°C by linear extrapolation.

TABLE 3

Z	T	V	M	$\frac{G+F}{2}$	$V \times \frac{G+F}{2}$	$\Delta h_z = f(V,T,G,F)$ ±% about h_z
80	-63	400	1,38	0,1925	72,0	± 17%
		100	0,34	0,5157	51,57	
75	-52	300	1,01	0,2218	66,54	± 8%
		180	0,60	0,3153	56,6	
70	-42	220	0,72	0,2748	60,5	± 3%
		150	0,48	0,3790	56,9	
65	-32	150	0,48	0,3790	56,8	± 2%
		120	0,39	0,4550	54,6	
60	-22	120	0,38	0,4658	56,0	< 1%
		90	0,31	0,6185	55,6	
55	-12	90	0,28	0,6185	55,6	< 1%
		80	0,25	0,6890	55,2	
50	- 8	60	0,18	0,9472	56,83	< 1%
		70	0,21	0,8151	57,05	

Relative Variations of "H" in Terms of V

ρ and T standard
(Standard January 45° N)

$$h = \rho C_p V \frac{\gamma + 1}{2\gamma} \alpha (\overline{G} + \overline{F})$$

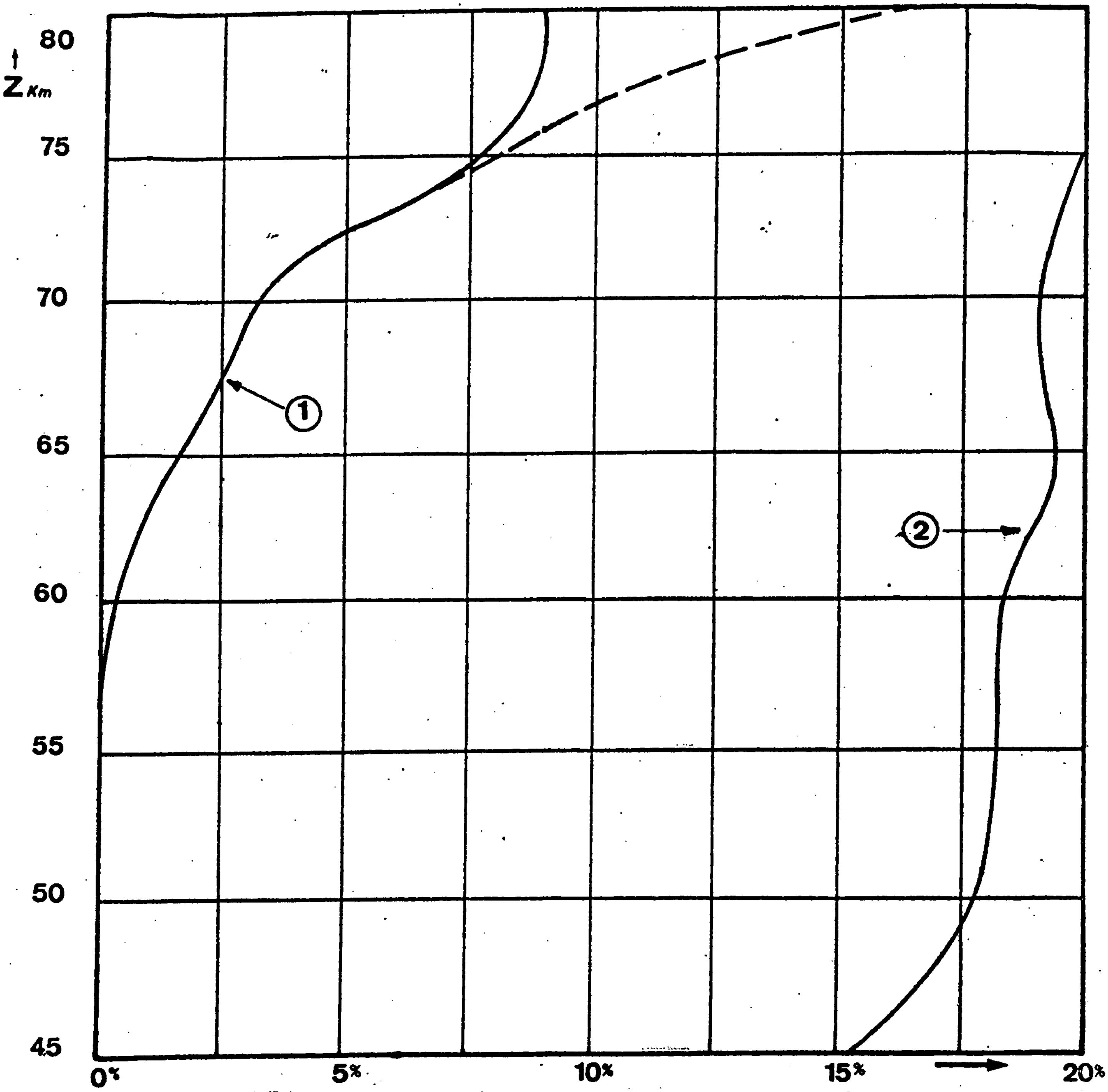

Figure 5. Curve (1): Relative variations of the coefficient of dissipation h in terms of V, T and G + F

$$\frac{\Delta H}{H} = f(V,\ T,\ \frac{G + F}{2})$$

-- only positive percentages are represented
-- there are two curves "summer" and "winter" since V varies (see Figure 3) winter: ____; summer: -----

Curve (2): Relative variations of the coefficient of dissipation "h" as a function of variations of density ρ at a constant level

3.2.3. Joule Effect

The formula is

$$\Delta T = \frac{R.i^2}{\pi.D.l.h} \tag{9}$$

The current measure is held constant and the power lost is always less than 2 μw. The minimum value of the coefficient of dissipation is around 1.7 μw. $mm^{-2}.C^{-1}$ at the highest levels corresponding to an elevation of temperature of 3.5°C at 80 km altitude.

The extreme values of ΔT as a function of variation of sensor resistance and of h are shown in Figure 6.

3.2.4 Time Constant

The formula

$$\tau = \frac{M.C}{h.A} \tag{10}$$

has an order of magnitude of the time constant which is several seconds at 80 km and decreases rapidly thereafter.

3.2.5. Radiation

3.2.5.1: Longwave radiation

At temperatures reached by the sensor or by the telemeter surfaces, radiation is found in wavelengths over 6 μ for which an experimental determination of the absorption coefficient k of the sensor is necessary.

The radiation term is

$$\frac{\Sigma_1}{A.h} = \frac{\sigma k(A_2T_2^4 + A_3T_3^4 + A_4T_4^4 - AT_f^4)}{A.h} \tag{11}$$

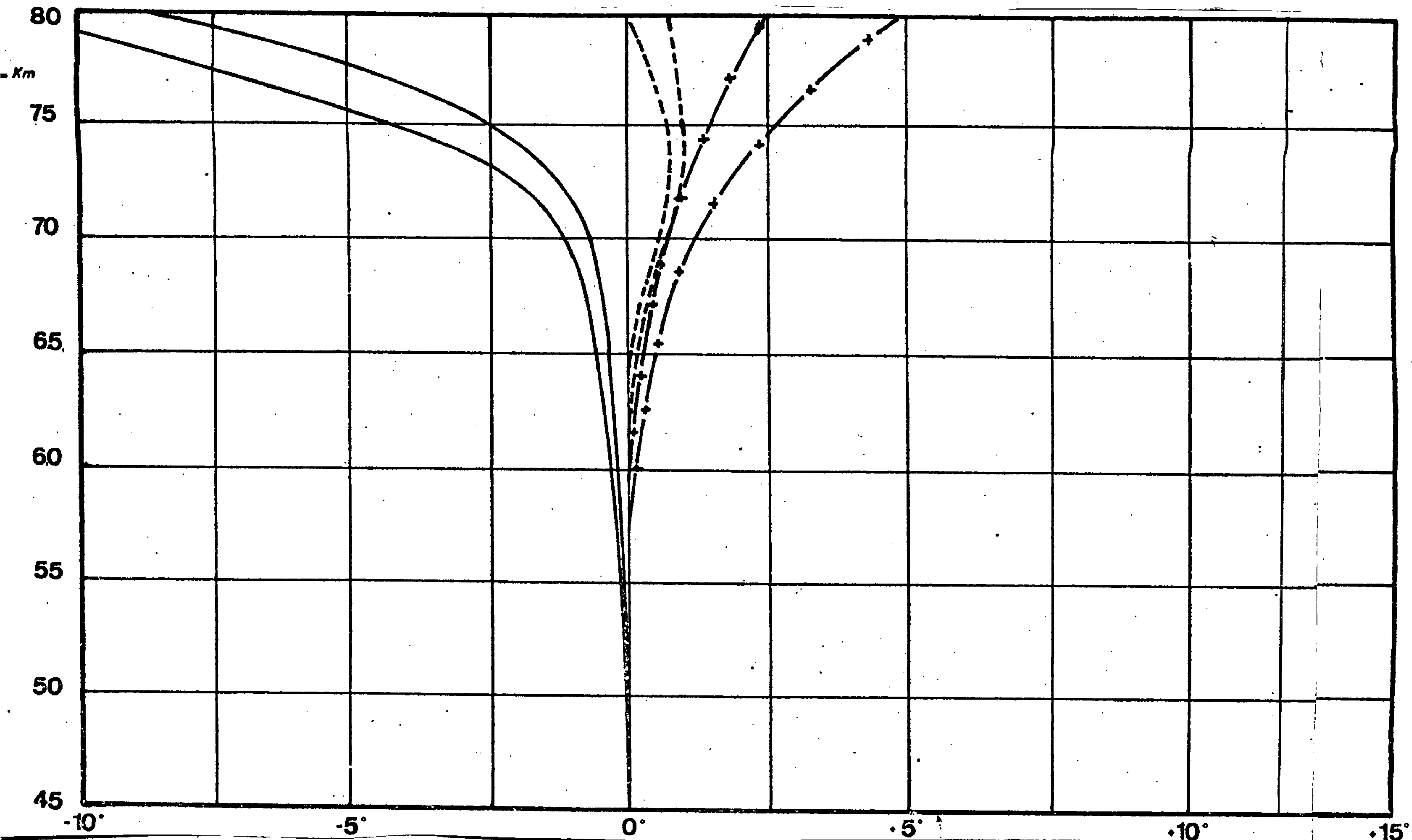

Figure 6. ——+——+—— Extreme values of heating by the Joule effect as a function of variations of R and h
----------- Extreme values of temperature correction caused by conductive heating
———————— Extreme values of long wave temperature correction

The values of temperatures used are those indicated by Wagner [5]. Temperature T_4 has been measured during many soundings.

T_2 = 249.6-0.09Z
T_3 = 123.3-1.25Z
A_2 = 0.5 A
A_3 = 0.48 A
A_4 = 0.02 A
T_4 = f(Z, T_f) (see Figure 7)
k = the mean value of the absorption factor of the sensor for wavelengths over 6 μ

Figure 6 indicates the extreme values of the radiation term as a function of Z taking into account variations in T_n, h and $\overline{T}_f$.

3.2.5.2. Short Wave Solar Radiation

The power received by the wire in the area of the sun is

$$k_1 \, I . A_1 \tag{12}$$

Theoretical determination of the absorption factor k_1 t k_1 for the entire solar spectrum remains quite difficult, and it is judged preferable to determine the temperature variations caused by solar radiation experimentally in the laboratory as a function of pressure for the case of a fixed wire perpendicular to the pertinent radiation. The extreme values of these variations in terms of different velocities encountered in the course of sounding are shown on Figure 8.

No consideration is made of the different possible orientations of the wire in relation to the direct solar radiation, nor of the terrestrial albedo.

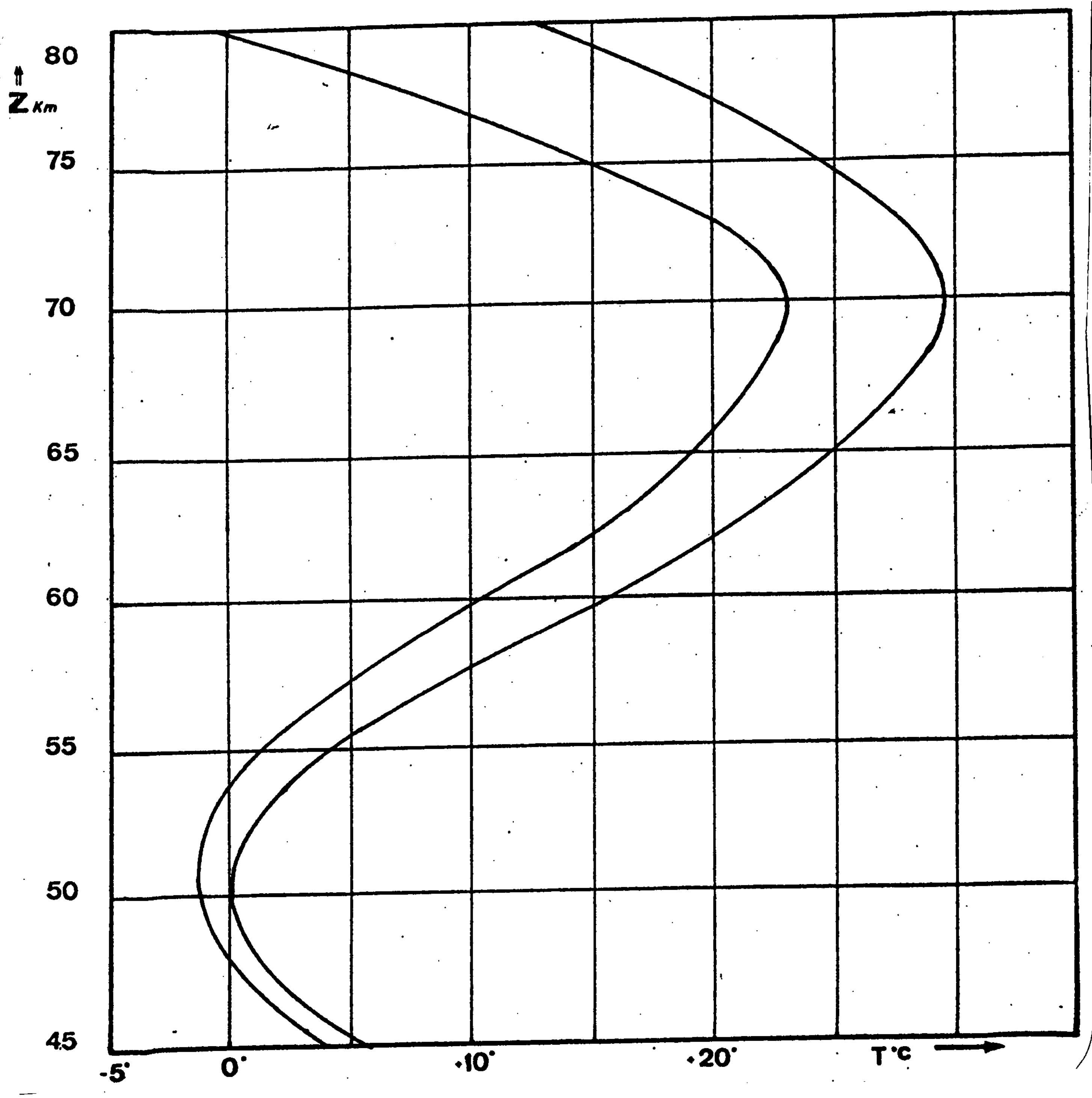

Figure 7. Extreme Values of the Difference ($T_4 - \overline{T_f}$) Between the Telemetry Surface Temperature "Seen" by the sensor and the Temperature of the Wire (Averaged over 1 km)

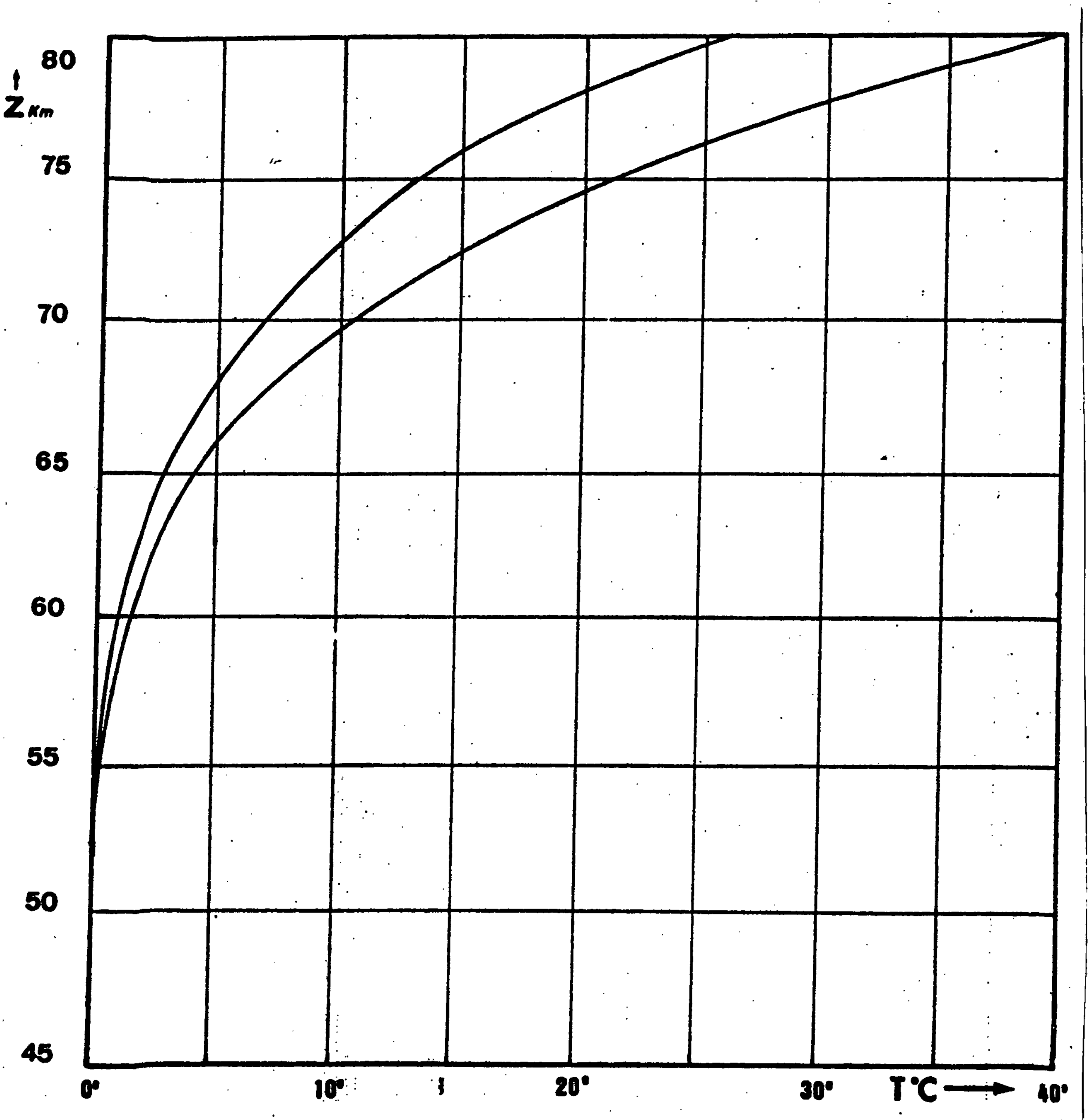

Figure 8. Extreme Values of Temperature Variation Caused by Solar Radiation as a Function of Variations in h

3.2.6. Conduction

Let: T_s = temperature of the supports

S_c = transverse cross section of the Constantan wire

K_c = thermal conductivity of the Constantan wire

h_c = the coefficient of heat exchange between the Constantan wire and the air

D_c = diameter of the Constantan wire

2L = length of the Constantan wire

Considering only exchanges by convection with the air, the distribution of temperatures along the Constantan wire during normal operation is shown by the equation:

$$T_x = T_e + (T_s - T_e)\left(\frac{e^{mx}}{1 + e^{2mL}} + \frac{e^{-mx}}{1 + e^{-2mL}}\right) \qquad (13)$$

$$\text{where} \quad m = \sqrt{\frac{h_c \cdot D_c \cdot \pi}{K_c \cdot S_c}}$$

the average temperature will be: $$\overline{T_x} = \frac{1}{L}\int_0^L T_x \cdot d_x \qquad (14)$$

Measurements made during the soundings (Figure 4) allow us to summarize the extreme values $\{T_s - T_e\}$

Applying the general equation of thermal equillibrium to Constantan wire (not considering heating by the Joule effect), equations (13) and (14) allow us to calculate temperature T_m for points between the Constantan wires and the thermal profile of the tungsten wire. The extreme values of this correction are shown on Figure 6. |6.

3.2.7. Kinetic Heating

A theoretical study of a wire replacing velocity V with the normal rate of speed of free molecules in a fluid of specific heat C_p has been performed by Oppenheim [6], who has published tables permitting us to calculate recovery factor r in the equation

$$T_r - T_e = \frac{rV^2}{2\ C_p} \tag{15}$$

where T_r is the recovery temperature and T_e -- the temperature of the air. An experimental calculation of this heating has been performed in our laboratories by placing a sensor and its apparatus at the end of an arm turning in a container in order to measure the velocity of displacement of the wire in relation to the air at 250 $m.s^{-1}$.

The equation of thermal equillibrium of the wire is written below in simplified form:

$$T_f - T_e = K\ V^2 \tag{16}$$

where T_f is the temperature of the wire, T_e -- the temperature of nonperturbed air and K the coefficient of kinetic heating as a function of the recuperation factor r and of the coefficients of exchange by conduction, convection or radiation.

The coefficient K has been found to vary little for this range of velocities and extrapolation to the high velocities likely to be found in the course of sounding should not cause errors greater than 10%. One series of experiments allowed us to study kinetic heating up to velocities of 400 $m.s^{-1}$.

IV. Determination of Density

Knowledge of the air temperature furnished by the sensor as a function of its geometric altitude determined by radar allows us to calculate pressure using the Laplace equation. We will investigate the simplified case of one dry atmosphere at a constant molecular mass.

Let: Z_i be the level in question

P_i -- pressure at Z_i

ρ_i -- density at Z_i

T_i -- temperature at Z_i

R_{T_e} -- the radius of the Earth

g_i -- acceleration of gravity at Z_i

M -- molecular mass of the air

R -- universal constant of ideal gas

Then:

$$dp = -\rho . g . dz \tag{17}$$

$$p = \frac{\rho . R . T}{M} \tag{18}$$

We can write

$$\frac{dp}{p} = -\frac{M}{RT} g . dz \tag{19}$$

Suppose the temperature gradient is constant between levels Z_i and Z_{i-1}, and that:

$$p_i = P_{(i-1)} . \alpha_i \tag{20}$$

The coefficient α is expressed as:

$$\alpha_i = e^{-\frac{M}{R.T(i-1)} \cdot g_0 \left(\frac{R_{TE}}{R_{TE}+Z_{(i-1)}} \right)^2 \left(1 - \frac{T_i - T_{(i-1)}}{2.T_{(i-1)}}\right).(Z_i - Z_{(i-1)})} \tag{21}$$

Level Z_o and corresponding pressure P_o are calculated by comparison with one or several radio soundings taken at the moment of launching the probe rocket. The recovery zone of the data provided extends from 9 km to 30 km with the lower limit defined as a level more than 1 km below the tropopause.

Level Z_i in this zone corresponds to particular points of temperature defined as the points between which linear interpolation does not produce an error greater than 0.2°C (i.e., 1 Hz). After comparing the temperature profiles thus obtained, we determine one or more possible Z_o; final selection of level Z_o is made by comparing the density profiles obtained.

Outside this zone of recovery, levels Z_i correspond to particular points of temperature based on standard criteria. On an average, the number of particular points is from 100 to 150 in the zone of recovery for a total of 250 to 300 for the entire sounding.

V. Method of Operation

5.1. Comparison of the Order of Magnitude of Corrective Terms

Table 4 compares the various possible corrective terms expressed in degrees as a function of altitude. Each vertical column corresponds to one correction or one group of corrections. These values are shown as curves on Figures 6 and 9, each curve bearing the number of the corresponding column.

-- comparison of columns 3, 6 and 7 shows that the corrections to kinetic heating and radiation are an order of magnitude greater than the others.

-- the values shown in column 9 are the greatest possible. Their low values, difficult to measure, may be considered negligible up to the highest levels. They do, however, influence calculation of measurement accuracy.

TABLE 4

Altitude z	Conduction (1)		Joule Effect (2)		IR Radiation (3)		Solar Radiation (4)		Kinetic Heating (5)		(1)+(2) (6)		(4)+(5) (7)		Telemetry (8)	High Frequency (9)	Accuracy (10)	
80	0	0,8	3,5	5,0	-9,0	-11,5	25	40	10	90	3,5	5,8	35	130	0,1	1	10	25
75	0,8	1,0	1,5	2,8	-2,3	-4,6	13	21	20	50	2,3	3,8	33	71	0,1	0,5	7	12
70	0,6	0,8	0,8	1,2	-,65	-1,0	7	10	10	25	1,4	2,0	17	35	0,1	0	3,5	5
65	0,2	0,2	0,3	0,5	-,40	-,62	3	4	6	10	0,5	0,7	9	14	0,1	0	1,5	2
60	0	0	0,1	0,2	-,25	-,36	1,5	2	3,5	6	0,1	0,2	5	8	0,1	0	1	1,5
55	0	0	0	0	-,20	-,25	0,8	1	2,5	3,5	0	0	3,3	4,5	0,1	0		0,5
50	0	0	0	0	-,10	-,10	<1	<1	0,5	1	0	0	1	1,5	0,1	0		0,3
45	0	0	0	0	ε	ε	ε	ε	ε	ε	0	0	ε	ε	0,1	0		

Comparison of different possible corrective terms in the form of maximum and minimum values expressed in degrees. The values shown in columns 6 and 7 are sums of values in columns 1 and 2 and 4 and 5 respectively. The last column displays the accuracy of measurements.

negligible values

standard values

calculated values

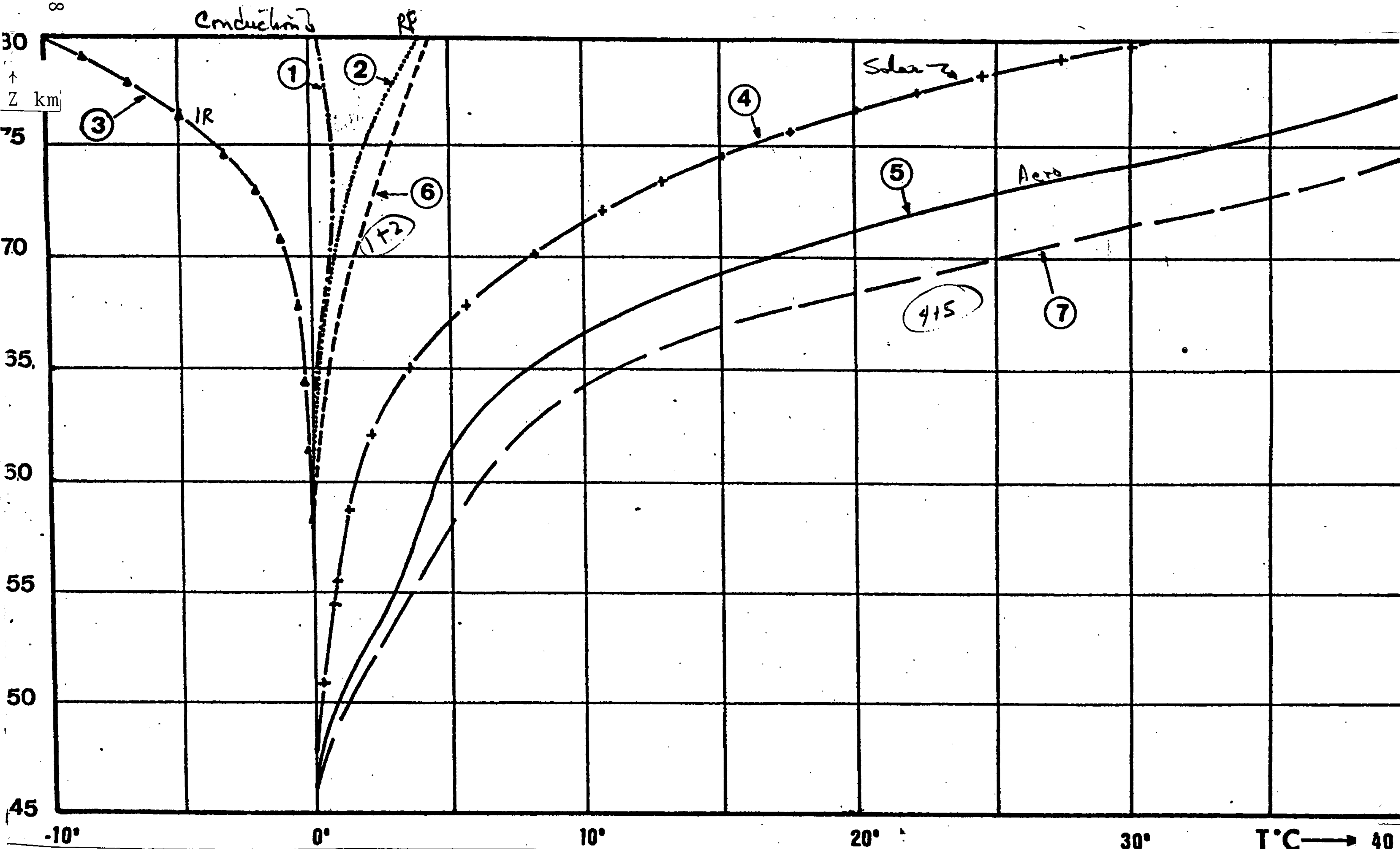

Figure 9. Comparison of mean values of possible corrections. The numbers of the curves correspond to the column numbers of Table 4.

5.2. Method of Analysis

Taking into account the residual error resulting from imprecision in calculating the corrections for kinetic heating and solar radiation, the actual instrumentation allows us to/

5.2.1. -- below 65 km:

a) ignore corrections required by:

-- heating by the Joule effect (column 2)

-- conduction (column 1)

-- infrared radiation (column 3)

-- influence of the temperature constant (s.2.4)

-- heating due to high frequency radiation in the area of the transmitter (column 9)

b) up to this level, use the standard curves providing corrections for solar radiation as a function of altitude;

5.2.2. -- above 65 km:

use the standard curves for corrections required by

-- heating by the Joule effect

-- conduction

-- long wave radiation

5.3. Accuracy of Measurement

The error inherent in the first term of equation (6) depends on the accuracy of estimation of the sensor velocity in relation to air V and the kinetic heating coefficient K. The radars used and the wind restoration methods applied give us an accuracy for V of 3% at levels above 70 km and 2% or less for levels below 65 km.

The accuracy for experimental determination of coefficient K varies from 10% for velocities of 250 m/sec to 5% for velocities less than 100 m/sec.

The accuracy of the whole first term relative to the kinetic heating correction will vary from approximately 16% for levels over 70 km to 7% for levels below 60 km.

The accuracy of the coefficient of dissipation h varies directly with all the other terms of equation (6). This coefficient is a function of density ρ, of velocity V and of the air temperature.

We can accept an accuracy of 2% for experimental determination of h and an uncertainty of 2% for estimation of h beginning with sounding data which corresponds to a final accuracy of calculation of the value of h of 4%.

In calculating the second term of equation (6) relative to the correction for solar radiation, the uncertainties of estimation of incident solar intensity, of experimental determination of corresponding temperature variations and of the application of these results to the conditions encountered during sounding do not permit an accuracy greater than 20%.

The third and fourth terms of equation (6) have an accuracy of approximately 5%, and the last term of approximately 10%.

The extreme values of these uncertainties calculated in degrees are shown in column 10 of Table 4, and we note that below 55 km the total uncertainty is less than 1 degree.

These estimations do not consider possible systematic errors caused either by the estimate of energy absorbed by the wire or by determination of the kinetic heating factor.

VI. Treatment of Information

6.1. Data Compiled (Table 6)

For each sounding we collect:

-- trajectory information provided by the tracking radar

-- rough frequencies as a function of time lapse of the sensors or of the resistances of references

-- a "temperature-resistance" calibration for the sensor used

-- a "resistance-frequency" calibration for the converter used

-- values of certain characteristic coefficients of the sensor used

-- a certain quantity of standard values of atmospheric parameters

6.2. Treatment of Output Data of the Trajectory Recorder

Calculation of the Wind

After sampling of the output data of the tracking radar at the rate of 10 positions per second, the first reading is made with a Sheppard operator of 2 degrees per 31 positions, and calculation of velocities and accelerations of the parachute is made.

After calculating the corrective terms of the wind, a reading of the average overlap for panels of 50 positions is made for the final components of the wind.

Table 5 presents the sequence of these operations.

6.3. Use of the Recorded Low Frequency Band

Frequencies in the "low frequency" band are recorded on a chart as functions of time at a rate of 10 Hz per centimeter which corresponds to 5 mm per degree.

The chart speed is 6 cm per minute during the first 30 minutes. This recording allows us to select particular positions of sounding.

6.4. Calculation of Corrected Temperature (Tables 6 and 7)

6.4.1. Soundings Limited to 65 km

Considered in calculations are:

-- frequency of particular positions as a function of time

-- values of resistances of the reference

-- converter calibration

-- sensor calibration

TABLE 5

Flow Chart of the Method of Treatment of Data Provided by the Wind